Ballast Water Review: Impacts, Treatments and Management

[1]Alaa Mohamed Ibrahim and [2]Manal M.A. El-naggar

[1]Arab Academy for Science, Technology and Maritime Transport Alexandria, Egypt
[2]Microbiology Laboratory, Marine Environmental Division,
National Institute of Oceanography and Fisheries, Alexandria, Egypt

Abstract: Stability is necessary for a ship to sail safely. For this reason, seawater is collected and taken to the bottom of the ship and stored in specially made compartments. This water is used to maintain the ship's stability and it is known as ballast water. This practice of pumping ballast water not only provides stability, it also reduces stress on the hull, improves propulsion and maneuverability and compensates for weight lost due to fuel and water consumption. So, this review will focus on some environmental manipulations of this ballast water beginning with its nature, important, impacts, treatments, managements and ending with its regulations through the international Maritime Organization (IMO) in order to emphasize our responsibility towards the protection of our marine environments.

Key words: Ballast Water · Impacts · Treatment · Management

INTRODUCTION

Oceanic transport accounts for more than 80% of total global shipments of commercial cargo (Figure 1). In addition to "intended" cargo, over 12 billion tons of ballast water is moved across vast coastal and oceanic domains annually [1, 2]. Ballast water is one of the primary vectors responsible for the global transport of vegetative- and resting-stages of aquatic microorganisms as well as for potentially pathogenic bacteria, such as *Vibrio cholerae* O1and O139 [3]. Successful establishment of non-indigenous organisms can cause unwanted economic [4], ecological [5] and human health impacts [6]. To attenuate the risk of ballast water-mediated invasions, the International Maritime Organization (IMO) established mid-ocean ballast water exchange (MOE) guidelines in IMO [7].

Ballast water discharge (Figure 2) typically contains a variety of biological materials, including plants, animals, viruses and bacteria. These materials often include non-native, nuisance, exotic species that can cause extensive ecological and economic damage to aquatic ecosystems.

Ballast water discharges are believed to be a major source of invasive species in marine waters, thus posing public health and environmental risks, as well as significant economic cost to industries such as water and power utilities, commercial and recreational fisheries, agriculture and tourism [4, 8, 9].

The Importance of Ballast Water: Ships are designed and built to move through water carrying cargo, such as oil, grains, containers, machinery and people. If the ship is travelling without cargo, or has discharged some cargo in one port and is on route to its next port of call, ballast may be taken on board to achieve the required safe operating conditions. This includes keeping the ship deep enough in the water to ensure efficient propeller and rudder operation and to avoid the bow emerging from the water, especially in heavy seas. A good weight-to-volume ratio and is carried in separate tanks used just for ballast, or in empty cargo tanks. When a vessel is departing a port, water and any sediment that may be stirred up is pumped into the ballast tanks and released again when it takes on cargo at the next port [11].

Safety, weather conditions, a ship's load and the route taken are the primary factors that determine how much ballast water is taken on board a vessel. More ballast is necessary for ships to sit lower in the water during stormy weather, or to allow for passage under a bridge. Ballast water is also used to balance the ship as it uses up fuel during a long voyage, or during loading and unloading operations (Figure 3).

Corresponding Author: Manal M. A. El-naggar, Microbiology Laboratory, Marine Environmental Division,
National Institute of Oceanography and Fisheries, Alexandria, Egypt.
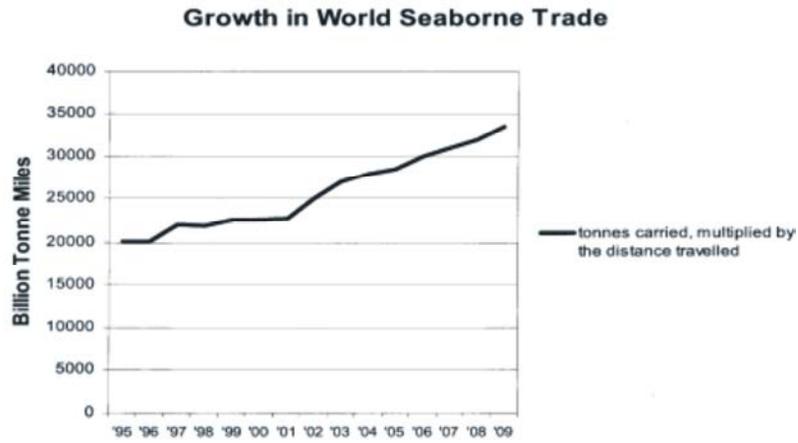
Growth in World Seaborne Trade

Fig. 1: The progress in the world seaborne trade during 1995 -2009 [2]

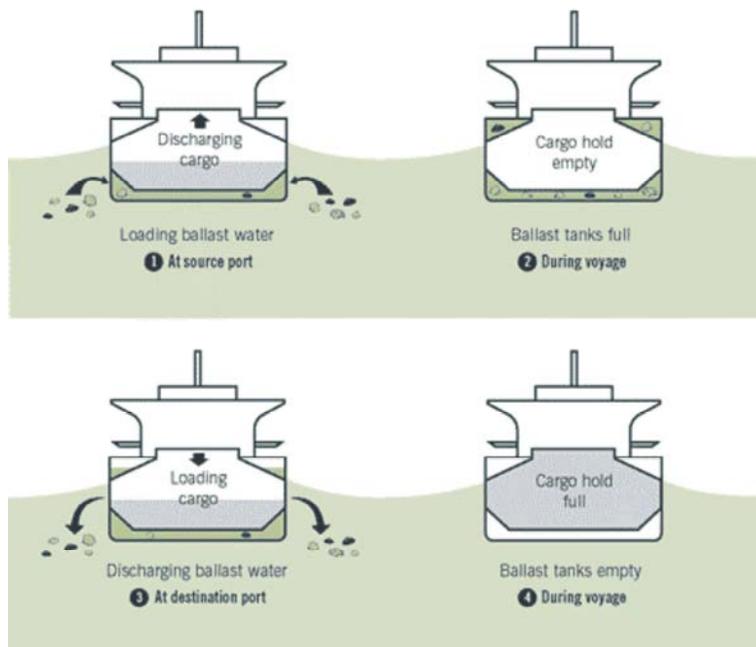Fig. 2: A photograph shows the discharge of ballast water from a container ship [10]

Fig. 3: A diagram shows the role of ballast water in loading and unloading process on a cargo ship [12, 13]

Table 1: The introduced species through annual ballast water transportation in the United States [16]

Taxa	Number of Species Introduced
Plants	25,000
Mammals	20
Birds	97
Mollusks	88
Anthropods	4,500
Microbes	20,000

Table 2: Annual associated damages and costs for controlling aquatic invaders resulted from ballast water transportation in the United States [16]

Species	Cost
Fish	$5.4 billion
Zebra and quagga mussels	$1 billion
Asiatic clam	$1 billion
West Nile Virus (WNV)	$1 billion
Aquatic plants	$500 million (Cost of mechanical and chemical aquatic weed control ranges from $2,000 to $6,000/hectare/yrs; once established, removal is very difficult.)
Shipworm	$205 million
Green Crab	$100 million

Problems of Ballast Water Transportation: Using water analysis methods and particle size analyzers, it has been found about 4,500 types marine organisms including plants; animals and bacteria are transported per day. These materials often include non-native, nuisance, exotic species that can cause extensive ecological and economic damage to aquatic ecosystems. It is believed that a marine species invades a new environment somewhere in the world every nine weeks. Apart from the threat that comes with the movement of marine life, there are also issues pertaining to overexploitation of living marine resources and physical alteration and destruction of marine habitats [14, 15].

The introduction and spread of alien invasive species is a serious problem that has ecological, economic, health and environmental impacts, including loss of native biological diversity (Tables 1& 2). The impacts depend on the origin of the organisms and the location of the point of discharge. Moreover fifty thousand species have been introduced in the United States, causing $137 billion in damages each year [16].

Impacts of Ballast Water Transportation: The vast majority of aquatic species carried in ballast water do not survive the voyage, as the ballasting and de-ballasting cycle and environmental conditions inside ballast tanks can be quite hostile to organism survival. Even for those that do survive a voyage and are discharged, the chances of surviving in the receiving environment may be further reduced, depending on environmental conditions and predation by and/or competition from native species. However, when all factors are favorable, an introduced species may survive to establish a reproductive population in the host environment. It may even become invasive, out-competing native species and multiplying into pest proportions [17].

Ecological Impacts: Should an introduced species become a successful invader in its new environment, it can cause a range of ecological impacts. These include: competing with native species for space and food, preying upon native species, altering habitat, altering environmental conditions (e.g. increased water clarity due to mass filter-feeding), altering the food web and the overall ecosystem and displacing native species, reducing native biodiversity and even causing local extinctions.

The United Nations Environment Program has identified invasive species in general as the second greatest threat to global bio-diversity after habitat loss and this was re-iterated at the World Summit on Sustainable Development in 2002. An important feature of the ecological impacts of harmful aquatic bio-invasions is that they are virtually always irreversible and generally increase in severity over time. In this regard it is worth comparing the impacts of aquatic bio-invasions with those of a better-known form of ship-sourced pollution; major oil spills. In a major oil spill, the ecological impacts are most likely to occur very quickly, be catastrophic and acute and highly visible.

However, impacts will decrease over time as the oil degrades and clean up and rehabilitation activities are undertaken. With an aquatic bio-invasion, the initial impacts may be non-existent to minor and invisible. However, as the population increases, the impacts will increase over time, in an insidious, chronic and irreversible manner. Unlike oil spills, for which humans have developed a huge range of response and clean-up options, once an invading species has established a viable population in a new environment, it is almost always impossible to remove (Figure 4). There are no recorded cases of successful control and eradication of aquatic invasive species that have established in open waters. The extremely limited cases of successful control and eradication have been when the invading species was
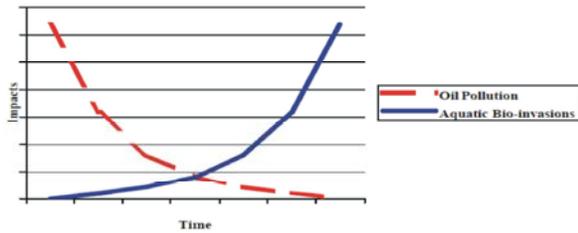
Fig. 4: Impacts over time, major oil spill versus aquatic bio-invasions [13]

detected at a very early stage, inside enclosed waters such as a marina or small bay, which could be closed-off and treated with biocides [13].

Economic Impacts: Many aquatic invasive species can cause major economic impacts on human society. Direct economic losses to society can be caused by aquatic bio-invasions in a number of ways, including:

- Reductions in fisheries production (including collapse of the fishery) due to competition, predation and/or displacement of the fishery species by the invading species and/or through habitat/ environmental changes caused by the invading species.
- Impacts on aquaculture (including closure of fish-farms), especially from introduced harmful algae blooms.
- Physical impacts on coastal infrastructure, facilities and industry, especially by fouling species.
- Reduction in the economy and efficiency of shipping due to fouling species.
- Impacts and even closure of recreational and tourism beaches and other coastal amenity sites due to invasive species (e.g. physical fouling of beaches and severe odors from harmful algae blooms).
- Secondary economic impacts from human health impacts of introduced pathogens and toxic species, including increased monitoring, testing, diagnostic and treatment costs and loss of social productivity due to illness and even death in affected persons.
- Secondary economic impacts from ecological impacts and bio-diversity loss.
- The costs of responding to the problem, including research and development, monitoring, education, communication, regulation, compliance, management, mitigation and control costs.

Table 3: Generic ballast water treatment technology processes [23]
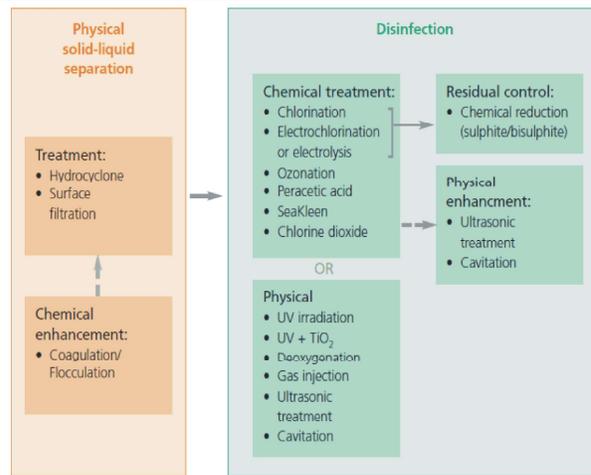
Ballast Water Treatment

The Criteria for Selecting a Treatment: The criteria for selecting a treatment method be can summarized as followed: the safety of the crew and passengers, the effectiveness at removing target organisms, the ease of operating treatment equipment, the amount of interference with normal ship operations and travel times, the structural integrity of the ship, the size and expense of treatment equipment, the amount of potential damage to the environment and the ease for port authorities to monitor for compliance with regulations [18-20]. However, ballast water treatment methods may have some negative effects on the ecosystem and/or the ship industry [21, 22].

The Major Treatment Methods of Ballast Water: The major treatment methods of ballast water were summarized in Tables (3 & 4) shows the mechanical removal of species in ballast water. They includes: filtration, separation unit, flow-through system, dilution method, sedimentation and flotation methods and ballast water exchange in Open Ocean. While the physical removal of species in ballast water were carried out through: heat treatment, cooling treatment, Ultraviolet radiation, Gamma radiation, Ultra-Sonics, Microwave, rapid pressure changes, electrical removal of species in ballast water and magnetic fields. In addition, the chemical removal of species in ballast water can be applied through: Chlorination, Metal ions, Ozone, Hydrogen peroxide, Oxygen deprivation (de-oxygenation), Coagulants, pH adjustment, Alternating salinities in ballast water and area of discharge, Antifouling paints as ballast tank coatings and Organic biocides [23-28].

Table 4: Comparative assessment of performance characteristics of different alternative technologies for treating ballast water [30]

Criteria	BWE	Filtration	UV	Ozone	Chlorine	Vacuum Deoxygenation	Nitrogen Deoxygenation	Biological Deoxygenation*
Energy cost	Small	High	High	High	Medium	High	Medium	Null
Risk to safety	Medium	Medium	High	High	High	High	High	Null
Training personnel	Low	Medium	High	High	High	High	High	Low
Effect on ship lifespan	Almost null	Null	Null	Corrosion	Corrosion	Positive	Positive ?	Positive
Possibility for change	Yes	No	No	No	No	No	No	Yes
Environmental impact	?	?	Null	Null	Unacceptable	Acceptable	Acceptable	Acceptable
Equipment space (m^2)	Null	10	4	15	2	8	4	Null
Perishable space (m^2)	Null	Some ?	0	0	?	0	0	0.4

*Based on 200 L vessel trials.

BWE: ballast water exchange

Table 5: IMO *D2 standards for discharged ballast water

Organism category	Regulation
Plankton, >50 im in minimum dimension	< 10 cells / m^3
Plankton, 10-50 im	< 10 cells / ml
Toxicogenic *Vibrio cholera* (O1 and O139)	< 1 cfu** / 100 ml
Escherichia coli	< 250 cfu / 100 ml
Intestinal *Enterococci*	< 100 cfu / 100 ml

* D2: ballast water treatment process ** colony forming unit

Alternative Treatment Methods: Unlike the invasion taken place in terrestrial plants [29], the transport and discharge of ship ballast water has been recognized as a major vector for the introduction of invasive species. Chemical oxidants, long used in drinking water and wastewater treatment, are alternative treatment methods for the control of invasive species currently being tested for use on ships. One concern when a ballasted vessel arrives in port is the adverse effects of residual oxidant in the treated water.

The most common oxidants include chlorine (HOCl/OCl-), bromine (HOBr/OBr-), ozone (O_3), hydrogen peroxide (H_2O_2), chlorine dioxide (ClO_2) and monochloramine (NH_2Cl). This study was undertaken to evaluate the sunlight-mediated photochemical decomposition of these oxidants. Sunlight photodecomposition was measured at various pH using either distilled water or oligotrophic Gulf Stream water for specific oxidants. For selected oxidants, quantum yields at specific wavelengths were obtained. An environmental photochemical model, GCSOLAR, also provided predictions of the fate (sunlight photolysis half-lives) of HOCl/OCl-, HOBr/OBr-, ClO_2 and NH_2Cl for two different seasons at latitude 40° and in water with two different concentrations of chromophoric dissolved organic matter. These data are useful in assessing the environmental fate of ballast water treatment oxidants if they were to be discharged in port [31-33].

Ballast Water Management: Ballast water management can involve mechanical, physical, chemical and biological processes, either on their own or in combination, to remove, render harmless, or minimize the uptake or discharge of harmful aquatic organisms and pathogens within ballast water. Ballast water exchange, treatment or retention on board is considered to be best management practices for ballast water and accumulated sediment.

The followed Table (5) summarizes the standards and regulated values of microbial communities estimated for discharged ballast water by IMO [7, 34].

Ballast Water Exchange: Mid-ocean ballast exchange that occurs 200 nautical miles from shore in waters that are at least 2,000 metres deep currently provides the best available option to reduce the risk of alien species introduction and transfer; however, it is subject to serious ship safety limits [35, 36].
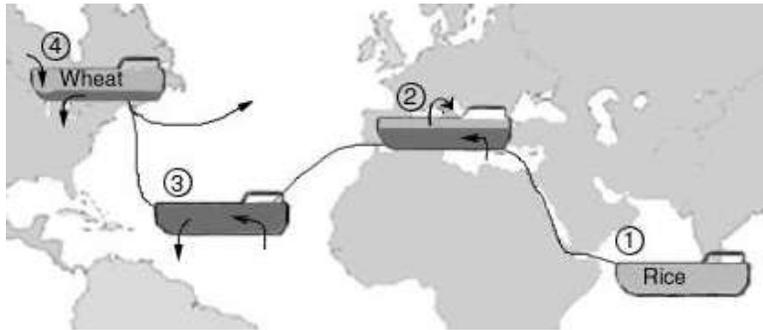
Fig. 5: Illustration for how ballast water exchange would work, A shipleaves a port in the Indian Ocean, travels through the Suez Canal, discharges cargo in the Mediterranean and takes up ballast water prior to crossing the Atlantic Ocean. Ballast water exchange would occur in the Atlantic prior to the ship entering the Great Lakes to pick up cargo, e.g. wheat for transport to the receiving port. [18].
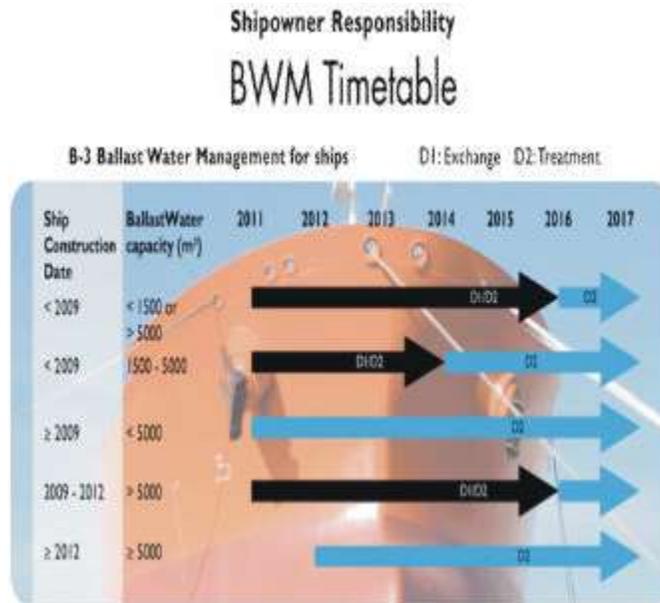

Fig. 6: IMO proposed diagram shows the time table for ballast water management (BWM)

Figure (5) illustrates how ballast water exchanged from one place to another. For example, a ship leaves a port in the Indian Ocean, travels through the Suez Canal, discharges cargo in the Mediterranean and takes up ballast water prior to crossing the Atlantic Ocean. Ballast water exchange would occur in the Atlantic prior to the ship entering the Great Lakes to pick up cargo, e.g. wheat for transport to the receiving port.

The principles behind ballast water exchange are that water taken from the foreign port is flushed out, thereby reducing the concentration of alien organisms in the ballast tanks and the high salinity level of the water (35 parts per thousand or greater) results in mortality to any remaining freshwater organisms. However, there is growing concern among scientists that freshwater organisms may be able to survive the saline environment created by mid-ocean exchange and there are examples of species that are salinity tolerant, such as alewives and the sea lamprey that normally spend parts of their lives in salt and freshwater. The two most common approaches to ballast water exchange are sequential exchange and flow-through exchange:

Sequential Exchange: It requires ballast water to be discharged until suction is lost and stripping pumps or eductors (an equipment used for suction or discharge) to be used if possible.

Flow-Through Exchange: It requires an entry and exit for the flow and involves pumping through at least three times the volume of the ballast tank.

International Convention for the Control and Management of Ships' Ballast Water and Sediments: Ballast water taken on in one ecological zone and released into another may introduce aquatic invasive species and non-indigenous organisms. This can drastically disrupt fragile marine ecosystems.

The International Convention for the Control and Management of Ships Ballast Water & Sediments was adopted by consensus at a Diplomatic Conference at IMO in London on Friday 13 February 2004 (Figure 6).

- Ships constructed before 2009 with a ballast water capacity of between 1500 and 5000m^3 must conduct ballast water management that at least meets the ballast water exchange standards or the ballast water performance standards until 2014, after which time it shall at least meet the ballast water performance standard.
- Ships constructed before 2009 with a ballast water capacity of less than 1500 or greater than 5000m^3 must conduct ballast water management that at least meets the ballast water exchange standards or the ballast water performance standards until 2016, after which time it shall at least meet the ballast water performance standard.
- Ships constructed in or after 2009 with ballast water capacity of less than 5000m^3 must conduct ballast water management that at least meets the ballast water performance standard.
- Ships constructed in or after 2009 but before 2012, with a ballast water capacity of 5000m^{3}or more shall conduct ballast water management that at least meets the ballast water performance standard.
- Ships constructed in or after 2012, with a ballast water capacity of 5000m^{3}or more shall conduct ballast water management that at least meets the ballast water performance standard.

CONCLUSION

The introduction and spread of alien invasive species is a serious problem that has ecological, economic, health and environmental impacts, including loss of native biological diversity. The impacts depend on the origin of the organisms and the location of the point of discharge. Existing technologies are capable to achieving the recommended standards proposed by IMO, but the primary challenge is to adapt these technologies for application to the conditions and operational requirements of ballast water discharges. While the

second and the third challenges are to accomplish these technologies in orderly and economical manners. However, because no one method has yet been proven to remove all organisms from ballast water, more research must be conducted into improving existing treatment methods, developing new methods and determining the effectiveness of combining ballast water treatment methods.

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